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EDITOR
C. A. CHANT
David Dunlap Observatory
Richmond Hill P.O., Ont.

ASSOCIATE EDITORS
R. MELDRUM STEWART
Dominion Astronomer
Ottawa

W. E. HARPER
Director of the Dominion Astrophysical Observatory
Victoria, B.C.

J. PATTERSON
Controller of the Meteorological Service of Canada, Toronto

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THE RELATION BETWEEN BRIGHT CHROMOSPHERIC ERUPTIONS AND FADE-OUTS OF HIGH-FREQUENCY RADIO TRANSMISSION

By R. S. RICHARDSON

IN October 1935 Dr. J. H. Dellinger of the National Bureau of Standards described some sudden and remarkable fade-outs of high-frequency radio transmission, affecting the daylight side of the earth and lasting for about fifteen minutes each. He suggested that the fade-outs might be connected with solar eruptions and urged that special efforts be made to observe the sun continuously to see if any unusual sun-spot activity occurred at the time of the next fade-out, which Dr. Dellinger believed might be expected after an interval of about 54 days.

An examination of the hydrogen and calcium spectroheliograms taken at Mount Wilson as part of the routine solar work showed that on three occasions bright chromospheric eruptions had been photographed within a few minutes of the radio fade-outs reported by Dr. Dillinger. Spectroheliograms had not been taken at the time two other fade-outs were observed. This agreement was so striking that it was decided to make special observations for several days before and after the date of the next predicted disturbance of radio transmission.

As already implied, one of the most curious features connected with the first four fade-outs was that they occurred at intervals of 53.4, 55.1, and 55.4 days, the mean being 54.5 days. This interval is

(A paper read at the meeting of the American Geophysical Union, April 28, 1937)

twice the synodic time of solar rotation in latitude 16°, although the agreement may be only fortuitous. The first observing program was accordingly set for the latter part of October 1935. An eruption of moderate intensity was photographed on October 24, 54.9 days after the preceding fade-out and eruption. On October 10 the National Bureau of Standards noted a general improvement in radio transmission on the higher frequencies, which continued until October 21 to 23 when the upper limit of frequency reached the highest value they had ever observed. On October 24, however, the upper limit dropped to half its value on the preceding days, and then on October 25 returned to its previous high value.

A repetition of the phenomenon was expected about the middle of December. A brilliant eruption took place on December 16, 53.0 days after October 24. Since no immediate report of a fade-out came to our attention, it was at first believed that this constituted an outstanding example of an outburst of major importance with no accompanying disturbance in radio transmission. Recently, however, we have been informed that a fade-out occurred within five minutes of the exposure on which the eruption could first be discerned, so that there was no break in the series, as previously stated by the writer to have been the case.

The next disturbance was experienced on February 14, 1936, when a wide-spread fade-out began at $15^h\ 18^m$ and lasted from twenty minutes to five hours, depending upon the frequency. Clouds prevented observations at Mount Wilson, but the Huancayo Magnetic Observatory of the Carnegie Institution of Washington reported an eruption to be already in progress when they started their regular spectrohelioscopic observations at $15^h\ 30^m$.

Another fade-out and a bright eruption took place 54.1 days later, on April 8, and again on June 3, after an interval of 56.0 days. Although a minor fade-out was noted 53.0 days later, on July 26, the cycle evidently ended on June 3; at least the important disturbances of radio reported since then have not been in accordance with any simple and obvious law.

The observing program in October and December 1935 and April 1936 consisted simply in taking hydrogen spectroheliograms about every five minutes, unless interrupted by clouds or instrumental ad-

justments. Beginning in May, Dr. Seth B. Nicholson installed a camera adapted to take spectroheliograms automatically on 35 mm motion picture film. The interval between exposures is ordinarily about four minutes, while the actual time required for the image to pass across the slit and thus complete the exposure is about fifty seconds. The machine is started soon after sunrise and operates continuously with very little attention until shut off about an hour before sunset. Hence, we have nearly complete records of the appearance of the sun on all clear days at Mount Wilson since May 1936. Sufficient data now exist to make a discussion of the material worthwhile.

A comparison of the radio fade-outs from April, 1934 to February, 1937, with the chromospheric eruptions photographed at Mount Wilson during that interval, reveals thirty-four coincidences so close that the probability of a relation between the two seems very strong. Other close coincidences have been observed at Greenwich, but only our own material will be discussed in detail here.

In fourteen cases, the time when an eruption was first seen agrees to within two minutes or less with the time when the fade-out began. In all fourteen cases solar observations had been made shortly before the fade-out occurred, the longest interval being ten minutes. If an eruption and a fade-out were actually observed to begin simultaneously, it would seem highly probable that energy emitted from the solar eruption with the velocity of light is the direct cause of the fade-out. The evidence to this effect is particularly strong for the disturbance on April 9, 1936. A spectroheliogram taken at $16^h\ 22^m$ G.C.T. was quite normal. The next plate taken at $16^h\ 47^m$ showed that an unusually brilliant eruption had in the meantime occurred over a large spot-group near the central meridian. From the appearance of the bright flocculi and from previous knowledge of such eruptions it was estimated that the outburst began only a few minutes before the exposure was made. This estimate was confirmed later by a statement from the Huancayo Magnetic Observatory in Peru maintained by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The observers at this station witnessed the eruption with the spectrohelioscope, noting the first signs of activity at $16^h\ 43^m$. A major fade-out was experienced at

$16^h\ 46^m$, which lasted from 15 to 30 minutes for various radio frequencies.

Twelve of the eruptions have apparently preceded the fade-out by from four to seventeen minutes. The best example was on August 30, 1935. A sudden fade-out took place at $23^h\ 20^m$. Examination of a series of exposures taken every four minutes from $22^h\ 30^m$ to $23^h\ 30^m$ indicates that the eruption started as early as $23^h\ 00^m$, and at $23^h\ 8^m$ had become very bright. Here at least twelve minutes seems to have elapsed between the time the eruption was well under way and the beginning of the fade-out.

For the eight remaining fade-outs, observations were not made until nine to thirty minutes after the radio disturbance began, when eruptions were found to be already in progress. It seems probable that earlier observations would have shown the eruption occurring slightly before, or at the time of, the fade-out. No fade-out is definitely known to have preceded an eruption with which it was obviously connected.

Disturbances of the earth's magnetic field and chromospheric eruptions occurred simultaneously with the radio fade-outs of November 28, 1934, February 14, April 8, November 8, 24, 26, 27 and December 24, 1936. The disturbances of the earth's field as recorded at Mount Wilson all consist of a sudden decrease of about 10 gammas in the horizontal intensity, accompanied by a change in declination of about 3′ toward the east. These changes should not be confused with those characteristic of magnetic storms, which frequently last for several days with fluctuations in horizontal intensity and declination often twenty times greater than those accompanying a radio fade-out. There is evidence that magnetic storms may also be caused by chromospheric eruptions, but with an interval of the order of 26 hours between the eruption and the commencement of the storm.

Spectroheliograms of the bright flocculi associated with radio fade-outs have been studied to see if they differ in any way from eruptions which do not coincide with known geophysical phenomena. The only distinguishing feature readily discerned is that nearly all the eruptions producing fade-outs are much brighter than the average. This is shown in a striking way by the tabulation below of the number of fade-outs that have occurred in connection with

chromospheric eruptions of different intensities. These intensities are simply eye-estimates made on the scale of 1 to 3, as adopted by the International Astronomical Union.

Intensity	Number of Eruptions	Coincident Fade-outs	Per cent
1	118	15	12.7
2	33	8	24.2
3	12	11	91.7
Total	163	34	20.8

Only once has an eruption of great brightness failed to coincide with a radio fade-out, and even this case may not be an exception. On December 24, 1936 a flare of intensity 2 was photographed at 22^h 35^m. At the same time our magnetometer recorded a sudden decrease in H of 3-γ, but no perceptible change in D. Radio fade-outs took place at 22^h 05^m and 23^h 50^m, but these were apparently produced by eruptions observed at nearly the same times.

Very little is known concerning the real brightness of the flocculi as it appears in H*a* and the H and K lines of calcium, with which our spectroheliograms are taken. Attempts have been made on several occasions to measure the intensity of bright hydrogen flocculi by photographic photometry. Observations are difficult to obtain owing to the evanescent nature of the phenomenon. The flocculi that we have photographed on calibrated plates have been about seventy per cent as bright as the continuous spectrum within a few angstroms of H*a*. Recently, however, a series of exposures in H*a* was found which had been taken in 1917 by Ferdinand Ellerman of the Mount Wilson Observatory, showing emissions from H*a* far more spectacular than any photographed later on. Unfortunately, the plate was not calibrated, but the continuous spectra on adjacent exposures overlap in several places, and the overlap is only slightly denser than the bright hydrogen emission. In this particular case then, the flare as seen in H*a* was almost twice as bright as the continuous spectrum nearby.

Of the thirty-four eruptions observed at Mount Wilson in connection with radio fade-outs, twenty-one have occurred in the southern hemisphere in mean latitude 21°, and the remaining thirteen in the northern hemisphere in mean latitude 20°. The mean distance of the thirty-four eruptions from the center of the sun's disk is 0.74; the mean distance of the 149 bright eruptions observed during the

same interval, is 0.67. So far, the eruptions have shown no definite tendency to favor a particular region in heliographic longitude. It has long been known, however, that very large magnetic storms are more frequent when large active spot-groups are near the central meridian. This circumstance is naturally explained if we may assume that radio fade-outs are caused by radiation and magnetic storms by charged particles ejected radially from sun-spots with a high velocity. Radiant energy would reach the earth regardless of where it originated on the disk, but a stream of charged particles would not be likely to encounter the earth unless ejected from a spot near the central meridian.

The radiation producing the fade-outs seems undoubtedly to come from the outbursts that show so conspicuously on hydrogen and calcium spectroheliograms. A natural assumption would be to suppose that a small area on the sun, at a high temperature, emits large quantities of black-body radiation of high frequency; but direct observational evidence throws considerable doubt on this assumption.

For many years the spectroheliograms at Mount Wilson were taken with two slits set about 5 cm apart—one over the H*a* or the K2 line, the other over some part of the continuous spectrum. Two images are thus obtained simultaneously: a spectroheliogram in the light of H*a* or K2, and a monochromatic image resembling a direct photograph of the sun. In the course of the routine solar observing we have by chance photographed many bright eruptions. If these eruptions are associated with black-body radiation of high temperature, they should also show conspicuously on the monochromatic images taken at the same time. An inspection of many plates showing strong eruptions in H*a* or K2 fails to show any trace of a corresponding record on the images made with the continuous spectrum.

The question naturally arises why certain eruptions produce radio fade-outs while others do not. It is suggested that possibly the condition of the ionosphere, in addition to radiant energy from the sun, may be a factor in determining whether or not a fade-out of high frequency radio transmission occurs.

Mount Wilson Observatory
Pasadena, California.

CALIBRATING WATCHES BY THE STARS

By Homer A. Harvey

PERHAPS few of us would realize on first thought how essential to most of the activities of the human race is an accurate metering of Time. It is the most important job of hundreds of skilled scientists working exquisitely refined instruments in the observatories of every civilized country, and the prime concern of their governments—and governments are not noted for purely esthetic undertakings. Without accurate time there could be no safe navigation—and this is only slightly less true nowadays, with the advent of radio aids to navigation, than in the past, when all the great ocean highways were being laid out.

A timepiece in its simplest analysis is nothing more or less than a mechanism designed to take advantage of some *unchangeable* force or phenomenon in such a way as to mark *regularly recurring* intervals of time. This definition clarifies matters greatly, for we can at once name on the fingers of one hand all the eligible phenomena in Nature;—in fact, we may reduce them to two—*gravitation* and the *rotation of the earth upon its axis*. Others might be named which for various reasons have not up to now been utilized practically, but which may be called upon one day to furnish us with still more perfect clocks than we at present possess—for example, the vibration frequency of light and sound waves. The alternations of the electric current have already been made use of.

On first thought, gravitation might be considered the ideal constant force. But force must be converted into motion to record the passage of time, and motion means friction, and friction means heat, and heat means expansion, and so on to endless complications. A pendulum of a certain length will vibrate indeed, at a certain rate at a certain distance from the centre of the earth, that is, at a certain elevation above sea-level. But where is the material which will keep a constant length in the presence of varying temperature? Of course, ingenious compensations have *very nearly* solved the problem; but that word "nearly" has brought more gray hairs to scientists than

all the rest of the dictionary put together. It is at the same time their bugbear and their *raison d'être*.

Gravity clocks—that is, pendulum clocks—are unlikely to approach much nearer perfection than they now are. Thus, while it is marvellous enough as it is, their performance must be checked periodically against some more nearly absolute standard. Watches actuated by uncoiling springs are still more temperamental, for not only is a spring less constant than gravity, but its latent force must be translated into motion through an escapement, which is only another form of pendulum and subject to the same errors.

The best watches for carrying upon the person have errors up to 30 seconds a month. Stationary watches—chronometers—may run with a monthly error of only a second or two. Pendulum precision clocks have been made which will vary only a few seconds a year; naturally these must be kept under the most perfectly invariable conditions of temperature, air density and freedom from vibration, and are used only as standards for ordinary timepieces.

One might think that now that we have drawn the point so fine that any further sublimation would be merely "gilding the lily". And indeed it would be for practical purposes. But one must remember that if mankind had been content with "practical" purposes it would not to-day even be riding in automobiles, to say nothing of weighing and measuring the atom. The time interval we call a day, measured with an error of a second or two, would indeed be quite accurate enough for 99% of humanity; but for the other precious 1% it is crude and unthinkable. For the astronomers, the custodians of our time, an error of even a tenth of a second is anathema.

There is good reason for this, too, apart from any idealistic standards of perfection. An error in itself is not so bad—we are all subject to them. But an *uncorrected* error, or one of unknown amount, is quite another thing. A ship's navigator feels secure with a chronometer seconds out of the way, provided only that it bear upon its face a legend showing the amount of error, plus or minus, upon a certain date, together with the *rate* of gain or loss. But an instrument ticking away ever so merrily and looking up at him with a blank countenance which might equally well mean honesty or

hypocrisy would be something to get panicky about. He knows too well that an error in rate of only a tenth of a second a day would add up to three seconds in a month, and that those three seconds, translated into distance upon the surface of the ocean might mean as much as a mile, which is just another mile added to the uncertainty of his position.

We find ourselves in the dilemma of the hunter pursued by a buffalo bull upon a treeless plain—there simply *had* to be a tree! As Nature spared to posterity the hunter of that classic yarn, by providing the tree, so she has also provided the astronomer with a perfect master clock—the axial rotation of the earth. This phenomenon is about the nearest invariable event in the universe. Such minute irregularity as it is subject to is reducible to a known law, which is the next best thing to no error at all. Any visible results of this rotation, therefore, will have a periodicity which is perfection as far as is given to us mortals to know.

There remains only to choose the more suitable of the two rotational phenomena—the apparent passage across our sky of the sun and of the stars. The sun would be the natural choice, since we live by it rather than by the stars. Unfortunately, the sun is fully as imperfect a timepiece as the pendulum or spring clock. This statement may seem surprising, especially since we know that the sun's movement across our sky is the result, not of its own motion, but of the axial rotation of the earth, which we have just characterized as the most invariable of Nature's phenomena. Thus it might seem that the sun should cross (transit) our meridian, the midway line of our sky, at precisely noon every day. And indeed it would, but for one fact—the *additional* slow motion superimposed upon its daily motion by the revolution of the earth in its orbit. It is this troublesome increment which contains all the elements of irregularity that bedevil the precision-loving astronomer.

If we picture ourselves walking about a stake, with a ball on top on a level with our eye to represent the sun, and the horizon around us to stand for the background of stars, we may gain an adequate understanding of the problem. It will be clear that if we walk about the stake in the counter-clockwise direction, always keeping our left side toward it, we will in one complete turn about it see

the whole of the visible horizon pass by us in the *clockwise* direction. The stake has meanwhile maintained a fixed relation to us—opposite our left side. Now, to revert to our simile, the stars have made one revolution about us in a westward direction while we were making one revolution about the sun, occupying one year. We have witnessed the passage of one "star-day", but *no* sun time has elapsed, since it has remained in a fixed position in relation to us. The conclusion we draw from this experiment is the key to the whole puzzle of Time for the layman—as the earth goes circling about the sun, rotating meantime regularly upon its axis to cause the succession of day and night, we will find at the end of the year's journey that we have witnessed *one more* "star" day than "sun" days, and this *quite regardless* of the total number of days it may have taken us to make the circuit. Since it happens—the word is used advisedly—that it takes 365¼ sun days to circle the orbit, there must be 366¼ "sidereal" days in the same interval.

We may now separate definitely the two superimposed movements of the sun and stars across our sky, and relate each to its proper cause. The daily circuit is the result of our axial rotation, while the slow drift westward of the stars in relation to the sun is caused by our orbital motion. This drift will be seen to amount to 24 hours divided by 365¼, or about 4 minutes a day. This sums up to 6 hours every three months, and accounts for the new set of constellations which occupy our sky with every season.

If we live our lives and set our clocks by the sun, as most of us do, we shall consider this drift as a shift of the stars westward. But if we are astronomers, and concern ourselves with the stars, we shall be equally justified in looking upon it as a shift of the sun *eastward* among the stars. In either case we shall be right, but with one important distinction—in the first instance we shall keep "solar" time, and in the second "sidereal". It simply amounts to this, that a *sidereal* clock *gains* 4 minutes (actually $3^m\ 56.55^s$) a day over a *solar* clock.

One further distinction, and the most significant one in the matter of precision;—measured by a sidereal clock, any given star will cross the meridian at *exactly* the same indicated time every day, whereas measured by a solar clock, the sun will cross it at only

approximately the same time, namely, noon. The two principal reasons for this erratic behaviour of the sun may now be readily explained.

The first depends upon the peculiar shape of the sun's annual path among the stars. Everyone has observed the seasonal swing of the sun into the northern region of the sky in summer, and back to the southern part in winter. If the axis of the earth were *perpendicular* to the plane of the orbit the progress of the sun from month to month would be a due eastward one; it would always rise due east and set due west, and cross the meridian at the same altitude every day. There would be one season, varying only with the latitude. Fortunately, the case is different; the axis is *tipped* at an angle of 23½ degrees, and maintains a constant absolute direction, so that the sun's path when laid down on a map, appears as a sinuous line first above and then below the average line with the advance of the seasons (and indeed the cause of them). This path is called the ecliptic, and is shown in the accompanying figure.

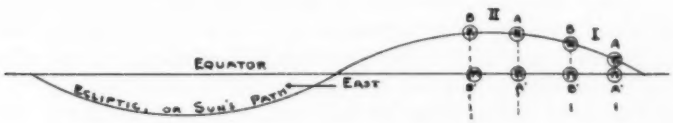


Fig. 1.—R, real sun; M, mean or fictitious; AB, equal in positions I and II; A'B', shorter in position I than in position II; position I, sun's place in April; position II, sun's place in July. The real sun is east of the mean sun in July.

By reason of this sinuous path it will now be seen that according to its place in it the sun may gain its daily 4 minutes either due eastward, northeastward or southeastward. Only at two seasons of the year will all the gain be eastward, as shown.

The effect of this is to make the interval between successive transits of the sun across the meridian *longer* than 24 hours at some seasons and *shorter* at others. This fact alone would be sufficient to disqualify the sun as a timepiece, but there is still another valid reason.

The earth's orbit is not a circle, but an *ellipse*, with the sun out of centre. The earth must therefore approach nearer to the sun at a certain time of year—oddly enough, in the winter—than at others. At this time it will travel at a greater orbital speed, on the same principle that an apple twirled at the end of a string will increase speed as the string is shortened. Greater orbital speed means more than average gain eastward of the sun.

The combined effect of these two irregularities is to produce two periods of the year when the sun is *ahead* of its average position, and two when it is *behind*. To meet this awkward situation astronomers have been compelled to invent a "fictitious" sun which shall travel, *not* in the ecliptic, but in the due eastward line (celestial equator), shall gain regularly its daily 4 minutes eastward, and shall therefore cross the meridian at exactly noon every day.

It is obvious that the real sun will thus cross the meridian ahead of or behind the "mean" sun by an amount called the *equation of time*. This may amount to as much as 14 minutes in February and 16 minutes in November.

Clearly "apparent solar time" is satisfactory only to those people for whom a matter of 16 minutes or so is of no importance. It was the farmers' time before the day of radio and telephone, but now it is useful only in locating the position of the mean sun, by the application of the equation of time, which is to be found in the Nautical Almanac, as also in the R.A.S.C. *Handbook*, for every day in the year. Mean time is in general use everywhere.

It would seem, now that he has reduced the rather unruly sun to submission, that the astronomer's task would be happily ended. But another problem at once presents itself. Every place of the same longitude upon the earth's surface has its own unique local mean time, good for no other meridian. Every degree east or west means a difference of 4 minutes faster or slower, respectively. Since a degree of longitude in the latitude of the New England States and lower Ontario is equal to about 50 miles, it follows, for example, that the time in Buffalo, 415 miles west of Boston, is almost 33 minutes slow of Boston time. This would naturally present an insurmountable problem for broadcasting stations and for trains operating between those points. This question came to a head more than 50 years ago

with the advent of transcontinental travel. At that time an official Congress of railway heads and astronomers adopted a plan for Standard Time Zones, originally five in number, now usually shown as four, approximately 15° wide, within each of which all time was to be uniform, and each zone to be one hour slower than its neighbour immediately to the eastward. This means simply that the difference arising from change of longitude is accumulated by common consent until it amounts to a full hour at the boundary of the zone, at which boundary all watches and clocks are changed to conform to the time of the new zone. Since the master reference time is that of Greenwich, England, Longitude 0°, it was agreed that these zones should each carry the time of the meridians which are multiples of 15°, representing differences of one hour. Thus Eastern Standard time is that of the 75th meridian, 5 hours slow of Greenwich time; Central of the 90th, Mountain of the 105th, and Pacific of the 120th. These meridians are approximately in the centres of their respective zones; the boundaries are laid down to pass through important cities and junction points lying near the theoretical location.

Once understood, this arrangement makes everything simple. A radio programme emanating from Los Angeles at 3 p.m. Pacific time, will be heard in New York at 6 p.m. Eastern time. A west-bound train passing Cincinnati, Ohio, will set its watches back one hour. An air-pilot trying for a Los Angeles-New York record will be careful to specify his time as "elapsed", or actual time consumed, by *his own* watch; otherwise a 20-hour trip, recorded in the time at the *terminals* would read 23 hours if flown eastward and 17 hours westward.

There remains to be noted the actual process of finding the local mean time with the greatest possible accuracy. The sun having been ruled out as a master clock, the astronomer has recourse to the stars, which constitute a perfect time mechanism and are in addition much easier of observation than the sun. The star is a *point,* whose transit across the meridian is ascertainable within much narrower limits than is the unsteady and brilliant edge of the sun.

The time standards for United States emanate from the Naval Observatory at Washington. Here is set up a highly accurate "transit" instrument whose sole use is in reading star transits for

the determination of time. The theoretical transit time of several hundred convenient stars is known to an accuracy expressed in thousandths of a second. The actual transit of the selected star is observed by a trained technician, and its precise instant recorded upon a moving drum side by side with the pendulum vibrations of the master clock. It is therefore possible to determine the time of transit, *as shown by the master clock*, to an error of around 1/10 second. The difference between this time and the theoretical time, as recorded in the Nautical Almanac, is therefore the error of the master clock, and this amount is indicated upon the record-sheet for the day.

The sidereal time thus found is then converted into local mean time for the meridian of Washington by a simple mathematical process. If it be remembered that sun time and star time *agree* at midnight about Sept. 23rd, and that sidereal time gains about 4 minutes a day over solar, it will be readily seen that the conversion consists essentially in multiplying the number of days elapsed since Sept. 23 by about 4 minutes and subtracting this quantity from the observed sidereal time. Thus, if the sidereal time at Washington on July 18, 298 days after Sept. 23, is 4h 30m the corresponding solar time will be approximately 298 × 4 min. (19h 52m) slower, that is, 8.38 a.m. The local mean time, derived with minute accuracy in accordance with this general principle, is then converted into standard time of the 75th meridian (E.S.T.) by a correction depending upon the distance of Washington from the meridian. (Washington Long. 77°3′W.; distance from 75th meridian, 2°3′; correction added for that distance 8m 12s.) This eastern standard time is then broadcast at convenient hours from the Observatory via Arlington radio station for the regulation of timepieces all over the country. The clicks heard in the radio are the sounds of the closing circuits made by the swinging pendulum of the broadcasting clock.

Batavia, N.Y.

THE UNITED STATES NAVAL OBSERVATORY

By Captain J. F. Hellweg, *U.S. Navy (Retired)*

(With Plates IV-V)

HOW would the Naval Service like to "walk back the cat" to the gay nineties with infrequent checking of chronometers when the ship happened to be in port and in touch with a Western Union Telegraph office; or, if in an isolated place, to send the assistant navigator ashore with an artificial horizon to make observations for chronometer corrections?

Our present-day methods and the lightning rapidity with which the navigator of to-day can obtain the exact error of his chronometers are a long step from the day when the superintendent of the Naval Observatory pushed a button that connected the Observatory with the fire alarm system of the capital.

The Navy as a whole knows little about the Naval Observatory except that it sends out the "tick" and publishes the *Nautical Almanac*. Few realize the effort that must be put forth continuously in order to insure the "tick" on time and the publication of books six months ahead of the date when they will be necessary for navigation.

Prior to 1830, the navigational requirements of ships were supplied by the purchase abroad through commercial agents, most of whom knew little or nothing about the requirements. Naturally, the results were far from satisfactory. Upon receipt, instruments were frequently found entirely unsuited, or useless; charts and publications were in foreign languages; longitudes were not reckoned from a zero meridian; and all required great effort and translation before availability for use in our naval service. When ships were decommissioned, their charts, navigational instruments, etc., were piled in a storehouse at the navy yard where they lay neglected until reissue. Too frequently they were found to have deteriorated, necessitating further purchase—and the cycle repeated itself.

From 1809, when an amateur astronomer, William Lambert,

This article is reprinted, by permission, from the *United States Naval Institute Proceedings*, Vol. 62, No. 10, October, 1936. Captain Hellweg is the Director of the United States Naval Observatory.

presented his memorial to Congress recommending the establishment of a first meridian at the permanent seat of government, until 1830, all efforts to establish a national observatory had failed. Lambert determined the longitude of Washington and submitted his calculations to Congress with his memorial. As late as 1835 the Secretary of the Navy invited attention to the vital importance to the government of establishing a naval observatory, its effect on the defense of the country, its great influence on the Navy and on our commercial and economic life as well as our scientific advancement.

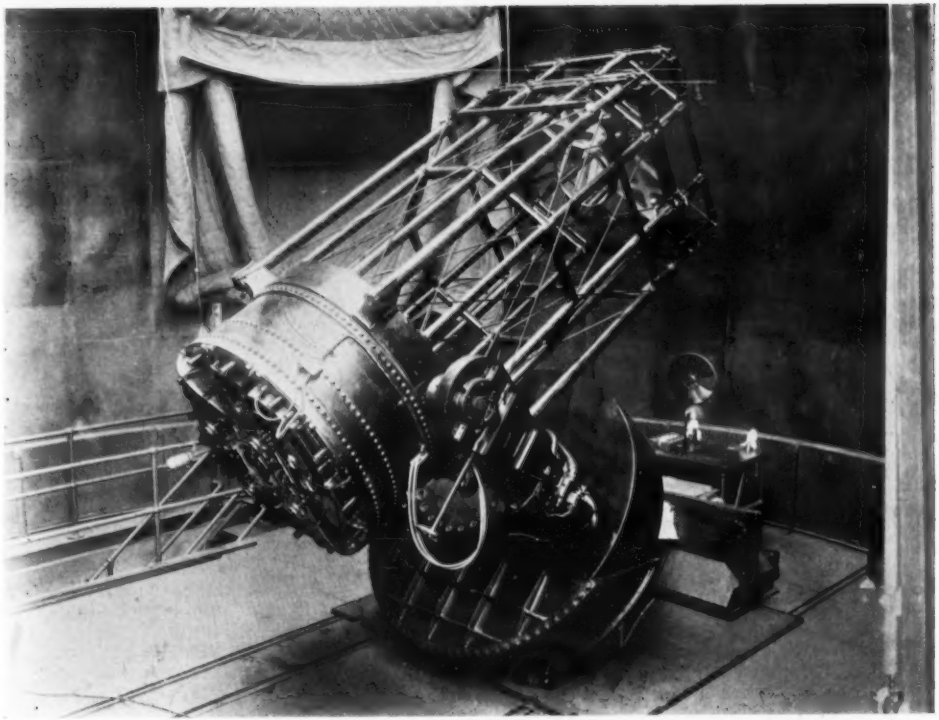
In 1830 the Secretary of the Navy upon recommendation of Lieutenant Goldsborough established the Depot of Charts and Instruments and placed that officer in charge. His duties were defined as: the determination of the errors of chronometers, the translation of all books, charts, pamphlets, and other nautical information into English, and the reduction of all charts to the meridian of Greenwich. In 1833 Lieutenant Wilkes, a scientist of note, relieved Lieutenant Goldsborough. Becoming incensed at the procrastination of Congress in providing suitable accommodations, Lieutenant Wilkes built his own observatory, 16 feet square, about 1,000 feet north of the Capitol, on Capitol Hill, with his private funds. Therein he mounted a transit, made by Troughton in England in 1815, and loaned to Wilkes by the Coast Survey. He also installed a 3½-inch portable telescope, a transit instrument, a sidereal clock, and other accompanying equipment. In 1835 a lithographic press was installed and chart production was begun. The following year he was sent to Europe to purchase scientific instruments to be used on his exploring expedition. Lieutenant Gilliss who relieved him purchased the necessary equipment and instruments for the inauguration of the series of constant observations in astronomy, magnetism, and meteorology. He obtained a portable 4½-inch achromatic telescope, equatorially mounted, a variation transit, a comet seeker, a sidereal chronometer, and subsequently a sidereal and a mean time clock. Observations with these new instruments began in 1838 and continued until 1842, thus laying the foundations of a permanent naval observatory.

Lieutenant M. F. Maury relieved Lieutenant Gilliss in 1842, and in 1844 moved all the equipment to a new and permanent building.

PLATE IV

AERIAL VIEW OF THE U.S. NAVAL OBSERVATORY, WASHINGTON, D.C.

PLATE V



THE FORTY-INCH RITCHY-CHRETIEN REFLECTOR, U.S. NAVAL OBSERVATORY

Wilkes was an astronomer, but Maury devoted his time to the development of the hydrographic and meteorological work. He laid the foundations for the present internationally known system of hydrographic information and publications and established his fame as an oceanographer. One year later he began the systematic observations of the sun, moon, planets, and brighter stars, which have been continuous. In 1846 Maury published the first volume under the remarkable title *The first Volume of Astronomical Observations ever issued from an Institution Properly Entitled to the Name of Observatory on this Side of the Atlantic.* The work of the Naval Observatory was soon noted throughout the astronomical world. It was at the Naval Observatory, in 1847, that the planet Neptune, which had been discovered in 1846, was found to be the same star which had been seen twice by the French astronomer Lalande in 1795. Based on the Naval Observatory's determinations, the orbit of Neptune was reduced with great accuracy.

Between 1854 and 1860 three minor planets were discovered by the Observatory. In 1873 Congress appropriated money for the purchase and installation of the 26-inch refractor telescope. At the time of its installation it was the largest telescope in the world. It became famous in August, 1877, as the instrument with which Professor Asaph Hall discovered the moons of Mars.

The Naval Observatory was the first to use the telegraph in the determination of longitude between Baltimore and Washington and later between Havana and stations in the United States. In September, 1903, the Navy began the installation of the first broadcasting apparatus in Navesink, New Jersey, and in the spring of 1904 the broadcasting of correct time by radio signals on low power was inaugurated, followed in 1912 by broadcasting daily on high power from Arlington.

The mission of the Naval Observatory is stated: (1) to maintain continuous fundamental astronomical observations and calculations; (2) to prepare, publish, and distribute the *American Ephemeris, Nautical Almanac*, and other astronomical publications for maritime, commercial, and scientific use; (3) to derive, maintain, and disseminate the most accurate time for the national use; (4) to develop, procure, and supply navigational instruments and equipment for vessels and aircraft of the Navy; and (5) to contribute to the international advancement of navigation and astronomy.

This mission necessitated organizing a number of task groups, to each of which is assigned a definite objective, of which there are four: (1) time service, (2) publication of nautical information for navigational purposes, (3) continuous observations of sun, moon, planets, and bright stars for positional astronomy, and (4) the development, procurement, and distribution of all navigational instruments for the naval service. Eighty per cent of these tasks are almost exclusively naval.

The Naval Observatory differs from all other American observatories in that the astronomical work of the latter is along scientific lines for research and for instruction, while the Naval Observatory's work is fundamental astronomy, by which important work tables are computed and published. The *Nautical Almanac* and the *Ephemeris* are furnished for use in scientific, navigational, and commercial pursuits. The Nautical Branch is really the Materiel Section of the Bureau of Navigation. The task of this branch includes the preparation of all plans for the development, procurement, care, and issue of all navigational instruments.

The Naval Observatory is divided into two major branches: (1) the Nautical Branch, and (2) the Astronomical Branch. In addition to these two divisions, which might be considered our productive activities, there are the less attractive but necessary house-keeping activities. The Naval Observatory covers 72 acres in the best residential section of Washington. There are 55 buildings, some housing expensive instruments, all requiring upkeep.

Nautical Branch.—It is believed that the compass office, the time service, and the Nautical Almanac Office have the most far-reaching and immediate effect on the naval service. An error or a delay in any of these offices will be felt on every ship.

The compass division consists of two sections, the gyro section and the magnetic section. It is charged with the development, procurement, and repair of all compass material for the Navy, instruction of naval personnel, and the supervision of upkeep, etc.

The equipage division needs no explanation to the naval service. Everyone is familiar with the service navigational requirements. It is only necessary to note that all designs and details of navigational equipage under the Bureau of Navigation are controlled by

the Naval Observatory. In addition to its duties in connection with the development of navigational instruments, it is charged with the preparation of specifications, the review of reports from ships, and the final action on all surveys. A close liaison is maintained with the Bureau of Aeronautics in the development of instruments used for the navigation of aircraft. For these purposes it has been necessary to develop a corps of expert horologists and navigational instrument makers.

The aeronautical section is one of the most important and rapidly growing units at the Observatory. It carries on the research and experimental work in the design, development, and improvement of aeronautical, navigational, and meteorological equipment.

From the national point of view, probably the best-known activity at this institution is its time service. Many people can remember when every railroad system of this country had its own meridian, made its own time determination, and by that time operated its trains. The great trunk lines had to change their time from place to place to adapt their train time to the local time. The train times seldom if ever agreed exactly with the local time and the traveller was constantly in danger of missing his train owing to the resulting doubt and confusion.

The question of a universal standard time constituted one of the most troublesome problems that had to be solved by the Nautical Almanac Office in the early days. The Observatory's old files contain the following interesting records:

In 1864 the city of Washington introduced a telegraphic fire alarm system of which it was exceedingly proud. It was considered the last word in fire alarm systems. The superintendent of the Naval Observatory immediately perceived the opportunity offered to extend the usefulness of the Observatory by broadcasting time throughout Washington. Prior to that, the broadcasting of time was limited to the dropping of a time ball at noon on the Dome of the Observatory.

In the fall of 1864 the superintendent and Professor William Harkness communicated to the Hon. Richard Wallach, Mayor of the city of Washington, their plan to connect the Naval Observatory by direct wire with the central fire alarm office. After that the fire bells were struck at 7:00 A.M. and 6:00 P.M. by the Naval Observatory. In August, 1865, this first step in time broadcast was inaugurated.

At that time the State Department was housed in a building on upper 14th Street. Upon its urgent request a special wire was run from the central fire

alarm office to its main office so that the State Department could receive its own time signal over a private wire. The Western Union Telegraph Company, which maintained an office in the State Department building, had a wide-awake operator who immediately appreciated the situation and began transmitting a private signal to the Western Union's own central office every time he received a time signal in the State Department from the Naval Observatory. This is the origin of the Western Union Company's connection with the Observatory which has continued. In 1890 a memorial from the directors of 23 observatories requested a congressional investigation into the methods by which the Western Union Telegraph Company had a monopoly on the receipt of its time signals daily from the Naval Observatory.

The old records disclose a number of telegrams, letters, etc., from various communities, municipalities, etc., desiring to buy time. The city of Leavenworth, Kansas, wanted to buy time once a month and the mayor of that city, considered an outstanding progressive, was willing to pay for the time to be delivered to the principal jeweler in Leavenworth. The jeweler was to communicate the time throughout the city and also to the railroads.

In 1884, upon invitation from the United States, an international meridian conference was held in Washington and agreed to establish a single prime meridian for the entire world for the measurement of longitude and time. The meridian of Greenwich, already adopted by several of the leading maritime nations including the United States, was accepted.

Six years ago the Naval Observatory was broadcasting time manually three times a day with an accuracy of .01 or .02 of a second. It is now broadcasting time automatically 20 times a day with a possible least count of .001 of a second. An automatic apparatus containing a crystal clock, a chronograph, and an automatic broadcaster was designed and constructed, and for the past two years all signals have been automatically broadcast by this apparatus.

In order to insure maintenance of accurate time, a clock vault was designed and constructed four years ago. This time vault consists of two vaults, one within the other. The inner vault is separated from the outer vault by a 30-inch air space. Both vaults were designed to prevent the transmission of heat through their walls. Both are controlled by separate thermostats; the outer vault is heated by gas and the inner one by electricity. The

structure is fitted with regular magazine lighting. Each pier for each precision timepiece is oriented so as to be in the "dead angle" of adjacent piers to prevent the sympathetic influence of the swinging pendulums. Pressure and temperature are maintained constant.

To permit visitors to see the clocks "that keep the nation's time," an old periscope was obtained and was let down through the roofs of both vaults. During the last Navy Day "at home" over 2,000 people peered through the periscope which is used to make daily visual inspections of the operation of all the standard clocks.

The orthodox method of determining time by visual observations of the transit of stars has been abandoned. The Naval Observatory is the pioneer in the photographic determination of time. These developments have given the United States the most accurate time in the world. In the near future it is hoped that we will be able to determine time with an accuracy of .001 or .002 of a second.

The Navy is so well acquainted with the *Nautical Almanac* that a detailed description is considered unnecessary. The Nautical Almanac Office consists of four sections: the stellar section, the solar section, the lunar section, and the satellite section.

The *Nautical Almanac* and the *Ephemeris* have grown to such proportions that in order to avoid the expense and the needless duplication of the work an agreement has been reached by all the principal maritime nations of the world to divide the work and to exchange the output of each office. This international exchange agreement has proved excellent, the major part of the work being divided between Great Britain, France, Germany, and the United States. We are justly proud that most of the theories of the sun, moon, planets, and satellites, and the tables based on them by means of which the ephemerides are prepared, were developed in the Nautical Almanac Office of the United States Naval Observatory.

Within the past two years letters have been received from two of the principal maritime nations notifying this Observatory that after 1936 they will employ Naval Observatory formulas and methods in their determination of certain functions.

The *Ephemeris* is published three years in advance and the *Nautical Almanac* one year in advance to insure having on hand at all times, even on a long cruise, the current almanac showing the positions of the sun, moon, and stars, arranged for every day of the year.

The Astronomical Branch provides for continuous observations of the sun, moon, planets, and fundamental stars for the determination of absolute positions. This work includes the determination of the position of the equator and the equinox among the stars.

The following instruments are controlled by the various units:

40-inch Ritchey-Chretien Aplanatic Equatorial Reflector. This telescope, our most recent acquisition, is being used both visually and photographically.

26-inch equatorial refractor. Built in 1873 by the Warner Swazey Co. The object glass was figured by Alvan Clark, Cambridgeport, Massachusetts, and was used in the old Observatory in 1873. In 1877 this instrument discovered that Mars had satellites. The entire floor is an elevator and can be adapted to the height of the telescope after it has been set for observations. Used in observing occultations of stars by the moon.

15-inch photographic wide angle equatorial refractor. Not yet completed.

12-inch visual equatorial refractor.

10-inch equatorial refractor used in photographing asteroids.

9-inch transit circle.

6-inch transit circle.

5-inch photoheliograph.

The new 40-inch reflector is the largest example of that particular type of reflector in the world. It took over three years to construct, and only recently has been placed in service.

The 9- and 6-inch transit circles have been used for years in our fundamental astronomical work. The 6-inch has gained a reputation for excellence in positional astronomy exceeded by none. For years the 6-inch was used in time determination also, and averaged about 7,000 stars annually in fundamental work.

The P.Z.T. (photographic zenith tube) has been used for years in the determination of the variation in latitude. Several years ago it was modified for use in determining time photographically. This institution, as far as known, is the pioneer in photographic determination of time. The results have been uniformly excellent.

The 5-inch photoheliograph takes daily pictures of the sun and records all sun spots found. For years the Western Union Tele-

graph Company has maintained at its own expense a daily record of our sun spot data. They have found that there is a direct relation between the presence or absence of sun spots and the transmission of messages by wire.

Library.—The library contains about 35,000 volumes, exclusive of pamphlets. It has specialized in astronomy, mathematics, and allied physics, and has come to be recognized as one of the finest sources of information on these subjects. About 400 of the books were printed before 1800, half of these in the years between 1481 and 1700. Long, unbroken sets of scientific society publications range from the seventeenth and eighteenth centuries to the present.

Many people look upon the Naval Observatory as one of the show places of Washington. Last year there were approximately 7,100 night visitors who viewed the splendor of the heavens through our large telescopes; visitors total more than 12,000 a year. Schools and colleges as far north as Massachusetts make annual visits to the Observatory.

United States Naval Observatory,
Washington, D.C.

PRELIMINARY ORBIT OF THE SPECTROSCOPIC BINARY H.D. 96528

By J. F. Heard

THE star H.D. 96528 [Boss 2951, α 11^h $02^m.3$, δ $+23°52'$ (1900), vis. mag. 6.39, type A2] was first announced as a spectroscopic binary by Adams[1] in 1915 from the measures of four spectrograms, taken at Mount Wilson in 1914 and 1915, which yielded a range from -17 to $+32$ km./sec. Five spectrograms taken at Victoria in 1918 and 1919 yielded a range from -17 to $+8$ km./sec. and confirmed the binary character of the star.[2]

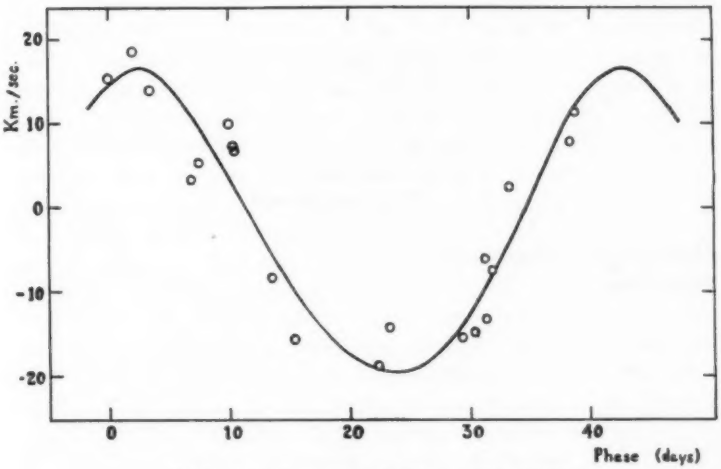
RADIAL VELOCITY OBSERVATIONS OF H.D. 96528

Plate No.	Date	J.D. 2428000+	Phase for P = 40.45 d	Vel.
704	1936 Mar. 26	253.664	0.000	+15.3
794	May 9	297.575	3.461	+13.8
813	" 16	304.585	10.471	+ 7.3
875	" 29	317.580	23.466	−14.3
883	June 4	323.611	29.497	−15.4
889	" 5	324.581	30.467	−14.9
898	" 6	325.571	31.457	− 6.1
919	" 13	332.599	38.485	+ 7.7
931	" 17	336.605	2.041	+18.5
1638	1937 Jan. 13	546.868	10.054	+10.0
1672	Feb. 4	568.788	31.974	− 8.3
1680	" 11	575.783	38.969	+11.2
1699	" 20	584.790	7.526	+ 5.2
1707	" 23	587.755	10.491	+ 6.7
1710	" 26	590.808	13.544	− 8.4
1715	" 28	592.751	15.487	−15.6
1741	Mar. 7	599.697	22.433	−18.8
1759	" 16	608.777	31.513	−13.3
1763	" 18	610.672	33.408	+ 2.4
1810	Apr. 1	624.649	6.935	+ 3.2

From March, 1936 to April, 1937 twenty-one spectrograms of H.D. 96528 have been obtained at this observatory, three with the spectrograph fitted with the 25-inch camera and eighteen with the

[1]Pub. A. S. P., 27, 132, 1915.
[2]Pub. D. A. O., 1, 295, 1921.

12-inch camera. The lines on these plates are of poor character but upwards to 24 lines are measurable, depending upon the density of the spectrum. The writer has measured the plates for radial velocities, rejecting only one as too weak to give a reliable result. The radial velocities, reduced to the sun, as yielded by the twenty plates are shown in the accompanying table.



Orbit of the Spectroscopic Binary H.D. 96528

From the velocities shown in the table a period of approximately 40 days was deduced. The five Victoria observations of 1918-19 among themselves fitted this approximate period and, combined with the observations reported here, served to fix the period as 40.45 or 40.25 days, depending upon how many cycles are to be considered to have elapsed between the two sets of observations. Dr. W. S. Adams very kindly supplied the four Mount Wilson observations of 1914-15 so that an attempt could be made to choose between the two possible periods. The Mount Wilson observations combined with the Victoria and Toronto observations favour the 40.45-day period but do not entirely rule out the possibility of the 40.25-day period. In view of the fact that several

years must elapse before further observations can remove the uncertainty as to period, it was decided to report at this time a preliminary orbit based on a 40.45-day period, using the twenty Toronto observations of 1936-37.

The orbit which best fitted the observations was chosen by R. K. Young's graphical method. The velocity curve corresponding to this orbit is shown in the accompanying figure. The orbital elements are as follows:

$$P = 40.45 \text{ days}$$
$$K + 18 \text{ km./sec.}$$
$$e = 0.10$$
$$\omega = 330°$$
$$\gamma = 2.9 \text{ km./sec.}$$
$$T = \text{J.D. } 2{,}428{,}294.094$$

David Dunlap Observatory,
May, 1937.

RADIO TALKS OVER CFCT, VICTORIA, B.C.

By W. E. Harper

No. 86.—TEMPERATURE CHANGES IN THE HIGHER ATMOSPHERE

(Sept. 17, 1935)

I

In my seven minutes this evening I shall consider the temperature at various levels in our atmosphere. The first six or seven miles is the region where storms occur and throughout it the air is always more or less in motion. This layer is technically known as the troposphere and it has its greatest depth over the equator and the least over the poles. Its average thickness is probably between six and seven miles. The density of the air is naturally greatest at the Earth's surface and falls off gradually as we go to greater and greater heights. Not only the density but also the temperature changes. It has always been considered that it is not the sunlight coming through the atmosphere that warms it so much as the heat radiations reflected back from the Earth. Naturally, then, the farther we get from the surface of the earth the cooler it should be.

For simplicity, let us assume that the temperature at the Earth's surface is 50° Fahrenheit. Over the whole earth extremes of 0° in winter are probably as common as 100° in summer so that 50°F. or 10°C. is a reasonable value to assume. Now from balloons sent aloft with recording instruments it is learned that the temperature falls about 10° Centigrade for every mile of altitude so that at a height of, say, 6½ miles the drop would be 65° and hence the thermometer would stand at −55°C. approximately.

Farther up, we enter the region known as the stratosphere where until some years ago it was generally thought the temperature was practically uniform and of the order of −53°C. as outlined above. A radical change in such notions was first effected by Lindemann and Dobson, who in 1922, from their studies of meteor tracks, showed that the temperature at levels above 35 to 40 miles was even higher than at ground levels. This conclusion has been confirmed

in various ways and its general acceptance carries with it the notion that the solar rays warm up the middle atmosphere in their passage through it. Briefly put, the temperature drops to −53°C. at the 7-mile level, remains constant to the 20-mile level, then gradually increases so that at the 40-mile level the temperature is higher than at the Earth's surface.

What do we know about the higher levels, say at altitudes of 200 miles? Here the density has diminished to a very low value but there is nevertheless a certain amount of atmospheric covering of gases in a very tenuous condition, gradually decreasing to the zero limit of empty space. Here solar radiation is more intense than at the 40-mile level because of not having suffered any absorption at all. Within the last year or two the study by radio methods of the daily and seasonal changes in phenomena connected with these high levels has revealed the fact that surprisingly high temperatures prevail here.

Most radio enthusiasts know something of the so-called Heaviside layer which at a height of about 63 miles is responsible for deflecting the waves from a broadcasting station around the Earth. The layer consists of ionized atoms, that is, atoms which are disrupted so that one or more of the electric charges bound to the nucleus are dissociated from it. Ultra violet light from the sun is largely responsible for thus smashing the atoms and providing a useful conducting layer. Without going into the matter too fully we can say that the ionizing process takes place just as our physical theory would predict. At any particular place it should be greater at noon than in the morning or evening and naturally should be greater in summer than in winter. At Victoria on June the 21st the Sun's altitude at noon is 65°, whereas on December the 21st its altitude is only 18°, and its less direct winter rays have less ionizing power. The close agreement between theory and observation can only mean that at the height of this layer, 63 miles, very little change of temperature—whatever such may be—takes place throughout the year, otherwise the ionization process would vary accordingly.

The method of determining the height of this Heaviside layer as well as the degree of its ionization consists of sending up radio waves of various frequencies. What we are particularly interested

in at the moment is the fact that by using a short wave length we can penetrate the layer. To use a homely illustration, if the waves are short enough they can wiggle through the obstructing atoms and electrons and escape. It was then discovered that such waves were reflected back from another ionized layer much higher up and from the time elapsed between the sending and the receiving of the signal the height of the newly discovered layer is known to be nearly 200 miles. This layer is much more ionized than the one at the lower level and is correspondingly more effective in long-range broadcasting when short waves are used. Amateurs were using these short wave lengths—thought to be of no great value by the professional—in sending messages across the ocean and were thus utilizing Nature's great sounding board 200 miles above us before its presence was known to us.

Studies upon this newly-discovered layer show no such agreement between theory and observation as found for the Heaviside layer. The winter ionization content is actually greater than the summer, the very reverse of what was found for the lower layer. This can only mean that at this level the density must be much lower in summer than in winter, or that the summer temperature must be much higher than the winter. The English physicist, Appleton, who is largely responsible for such experiments, concludes that the temperature on a summer day at the 200-mile level is over 900°C., a rather startling and novel idea.

No. 87.—TEMPERATURE CHANGES IN THE HIGHER ATMOSPHERE

(Oct. 15, 1935)

II

Last month we discussed how radio investigations had brought us corroboration of the fact that high temperatures exist in our atmosphere, at the forty-mile level and beyond. At a later date we may return to these radio investigations and see how studies of the static which sometimes is an annoyance to radio fans may yet serve

a useful purpose in giving us information helpful in weather forecasting. To-night we purpose simply to examine the causes of these high temperatures and note an interesting result thereof.

Let us repeat our findings of last month. From a ground-level temperature of the order of 10° centigrade the temperature diminishes about 10° for every mile we ascend in the atmosphere. This holds true for the first six or seven miles so that at the 6½-mile level we have a temperature of −55° centigrade. We have now reached what is known as the stratosphere where until recent years it was supposed the temperature remained constant no matter how high recording instruments could be taken. However, in our last radio talk, we learned that after the 22-mile level is reached the atmosphere begins to warm up again at about the same rate as it cooled after leaving the earth, namely about 10° per mile. Thus at the 40-mile level the temperature would be that of boiling water whilst at the 200-mile level the evidence presented on the last occasion seemed to indicate a temperature of over 900°.

How do these temperatures come about? In the first six or seven miles where there is constant mixing of the air between various levels the temperature is governed largely by the supply of heat received by contact with the warm ground. In the stratosphere and above there is no such mixing; it is a region of calm and there is little or no mixing with the air below. Here the temperature depends on the absorption and emission of radiation. Radiation from the sun—largely in the form of visible light—passes inwards through the atmosphere and an equal amount of energy passes outward from the earth in the form of dark heat radiation. Only certain gases in the atmosphere take part in this absorption and emission of radiation; nitrogen, for example, is nearly transparent to all types of radiation passing through the atmosphere, but oxygen, ozone and water vapour strongly absorb and radiate certain particular types, being transparent to others. Oxygen absorbs strongly in the ultra-violet; ozone absorbs radiations of rather longer wave-lengths, though still in the invisible ultra-violet region of the spectrum. It also absorbs in the yellow-green region and in the long-wave infra-red region. Between oxygen and ozone about six per cent of the

sun's energy headed our way is absorbed at very high levels in the atmosphere. Water vapour is transparent to nearly all the visible and ultra-violet radiation but strongly absorbs most of the long-wave infra-red radiation emitted by the earth.

The water vapour absorption is largely, though not entirely, confined to the lower few miles of atmosphere. If there were nothing present but water vapour it would absorb little energy from the sunlight but would absorb the infra-red radiation emitted by the earth and would bring the air to a temperature of about 50° below zero centigrade, at which value it would remain constant. Water vapour thus largely accounts for the temperature of the stratosphere for the absorbing action of oxygen and ozone takes place higher up. We thus see that the actual temperature at any level depends on the relative amounts of water vapour, oxygen and ozone which are present at that level.

An idea of the average amount of each in the atmosphere can be gained this way. If the atmosphere were formed into a layer of uniform density equal to that of air at the earth's surface, there would be a layer five miles thick. Four miles of this would be nitrogen, one mile would be oxygen, whilst the thickness of the ozone layer would be one-eighth of an inch. The amount of water vapour of course varies and its relative proportion is not so well known, particularly above the 12-mile level.

The amount of ozone varies also, being greatest in spring and least in autumn. Thus it seems to shift from the northern to the southern hemispheres and back again in keeping with the seasons being, as stated, always greatest in the spring and least in the fall for any particular place. Moreover, for any particular date it is greater in high latitudes than near the equator where it is a minimum. The amount of ozone in the atmosphere can be determined very accurately by the spectroscope and a co-operative program, using standardized spectroscopes of uniform design, has resulted in the facts above stated being brought to light.

Since the amount of oxygen remains constant and its vertical distribution is fairly well known and since, as just stated, we can

measure the amount of ozone spectroscopically it only remains to know the amount of water vapour present at each level to apply the laws of physics and calculate the temperature at such levels. Assuming reasonable or likely values of the water vapour content the calculation shows that there should be a marked rise of temperature of the air in the region above 25 miles, agreeing reasonably well with the results quoted at the beginning of this talk.

Such temperatures for the upper air fit in most beautifully with certain hitherto unexplained facts in connection with the transmission of sound. When a large explosion occurs, the sound is heard for many miles around, but not to such great distances as might be expected. That the sound is not heard farther away is largely due to the fact that sound travels faster in warm air than in cold air. Since in the lower atmosphere the temperature falls with increasing height, sound travels faster through surface air than through the air a little higher up. Thus the sound waves near the surface run ahead of those above with the result that the sound ray is bent upwards, away from the ground. Sounds in a valley are thus often heard more clearly on the surrounding hills than at places the same distance away in the bottom of the valley. Similarly in the case of very large explosions it is often found that while the sound cannot be heard for more than 20 or 30 miles around the explosion, it is heard again at places perhaps 100 miles distant.

The sound waves which are heard at these great distances are found to have taken some two minutes longer than they should have had they travelled directly through the lower atmosphere. It would seem, then, that the sound wave has curved gradually upwards until it reached the level where the air starts to get warmer again, at which level it is again bent downwards. By using special microphones it is possible to detect the waves from the firing of one big gun at a distance of a hundred miles or more. By measuring the time and the angle at which the down-coming sound ray strikes the earth most of the details as to height reached and speed attained can be calculated. Since the speed depends upon the temperature this gives us a method of determining the temperatures at the upper levels and these agree with those determined by radio methods.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

Summer Meteor Observations

Readers of the Journal are reminded that Perseid observations will be carried out during the first half of August. The three nights nearest the Perseid maximum are Aug. 10-11, 11-12, 12-13, with the probability of the third night being a little better than the first. The moon will be approaching the first quarter and so will be absent from the sky for the last part of the night when the meteors are more numerous. It is desired to lay emphasis on the observation of telescopic meteors this summer. General instructions for such observations will be published in the next number of the Journal. Maps and record sheets for the Perseid observations may be secured from the writer at the Dunlap Observatory, Richmond Hill, Ont. The absence of the moon from the sky during the week preceeding the Perseid maximum will make this an ideal time for meteor observations of all kinds.

The Progress of Meteoric Astronomy in the Soviet

An interesting letter has been received from Dr. Astapowitsch of the Astronomical Institute in Moscow. He mentions an expedition for the observation of meteors which was stationed on the Apscheron Peninsula on the shores of the Caspian Sea in August, 1936. The expedition was under the leadership of Dr. V. V. Fedynski and secured eight direct meteor photographs and two new meteor spectra. The cameras used had speeds of f/3.5.

Investigation in all branches of meteoric astronomy is being very actively pursued in the Soviet at the present time. Headquarters for this work is located at the Institute in Moscow and from the 27th. to 29th. of January, 1937, the second conference on cometary and meteoric astronomy was held here. At this time 32 papers were presented and it is planned to publish these along with the papers of the first conference which took place in 1935.

New Meteorites in the Soviet

Dr. Astapowitsch notes in the same letter that a new meteorite fell in the Ukraine near Kiev on the 2nd. of May, 1936. Another meteorite was found by Prof. P. L. Dravert near Omsk, Siberia. This latter had been well observed as a fireball on the 1st. of March, 1929, and its orbit is accurately known. The Akademie der Wissenschaften of the U.S.S.R. has recently obtained two new meteorites which fell in Siberia in 1935. One was found near Sungatsch and the other near Nikolajevka.

A New Book on Meteors

"Die Meteore", in German, by Prof. C. Hoffmeister, has recently been published by the Akademische Verlagsgesellschaft, Leipzig, price 8.4 RM. Prof. Hoffmeister is one of the world's leading authorities on meteors and this is the first general book on the subject which has appeared since the publication of "Meteors" by Prof. Olivier in 1925. Though the writer has had time to only skim very rapidly through this new book it seems to be an excellent summary of our present knowledge of meteors and there is a good bibliography at the end. It should prove invaluable to anyone who is interested in meteoric astronomy. P.M.M.

REVIEW OF PUBLICATIONS

Publications of the David Dunlap Observatory. Vol. I, No. 1.—Description of the Buildings and Equipment, by R. K. Young, pp. 56, University of Toronto Press, 1937.

This booklet is, as the nomenclature indicates, the first publication to be issued by the David Dunlap Observatory of the University of Toronto, which was formally opened a little less than two years ago, on May 31, 1935.

As commemorated in the publication, this magnificent observatory was the gift of Mrs. Jessie Donalda Dunlap, of Toronto, presented to the University in memory of her husband, who had been for a number of years a member of the Toronto centre of the Royal Astronomical Society of Canada, and as an amateur had taken a deep interest in astronomical matters.

With the name of Mrs. Dunlap must be associated that of Professor Clarence Augustus Chant, who for the last quarter of a century and more had looked forward toward the founding of a worthy observatory to be associated with his alma mater, and during the latter years had made it his main object of effort. It is not given to many of us to see our ambitions so completely and satisfyingly fulfilled. As Professor Emeritus of Astrophysics and Director Emeritus of the Observatory his friends will wish him many years of still fruitful endeavor in his residence on the Observatory grounds, visible in the background of the frontispiece.

Very important and, indeed, essential contributions were also made by Dr. R. K. Young, Professor and Director of the Observatory. His long practical experience first at the Lick Observatory, Mount Hamilton, and later at the Dominion Observatory, Ottawa, and the Dominion Astrophysical Observatory, Victoria, had peculiarly fitted him for the problems arising in the design and construction of the 74-inch telescope, the second largest in existence. He had already, while on the University staff, constructed with his own hands a complete 19-inch reflector, which now forms part of the equipment of the Observatory. It was thus no mere theorist, and

no amateur, who took in hand the practical problems of original equipment, and who now directs the activities of the institution.

The contract for the telescope and dome was given to Sir Howard Grubb, Parsons and Company, England. Incidentally the fact is brought out that Sir Charles Parsons (since deceased), who was head of the firm at the time the order was placed, was the youngest son of the Earl of Rosse, who built the famous six-foot reflector in 1845. The disk for the large mirror, of pyrex glass, was cast by the Corning Glass Works, of Corning, N.Y., and the spectrograph was built by Hilger.

The description of the instrument is given in some detail, as is the record of the tests applied to the 74-inch mirror, both in the maker's workshops and after mounting in Toronto. It would appear that the quality is of the very best. One of the novel features in the construction of this telescope is in the provision of no less than seven small laboratory rooms within the concrete piers, which are hollow. A number of variations from previous design, suggested by Dr. Young's experience, are described, and the many illustrations give a clear idea of the details of construction.

The main program of work at present under way is the determination of radial velocities of stars in and near the Kapteyn areas. Some 1600 spectrograms have been secured, of which about two-thirds have been measured. Direct photography at the Newtonian focus, mainly of variables in globular clusters, is also being carried on.

It gives pleasure to the present writer, as representing the oldest member of our still young family of Canadian observatories, to welcome into the working ranks our youngest sister, and to extend all best wishes for a long and glorious future.

R. M. S.

Annual Report of the Director of the Mount Wilson Observatory. Reprinted from Year Book no. 35 for the year 1935-36. Issued December 11, 1936.

To read the Annual Report of the Mount Wilson Observatory is almost to read a report of the progress of astronomy, so diversified is the field of the research there and so great is the volume of work.

Without quoting the Report verbatim it is hardly possible not to omit items of importance. In the following summary reference is made only to programs which have led to discoveries or conclusions of remarkable interest; it must be born in mind that steady advance is also reported along the lines covered by routine programs.

Extragalactic Nebulae. A new supernova in an extragalactic nebula of the Virgo cluster had, at maximum, a luminosity of 20 million suns. Its spectrum showed exceedingly wide emission bands in agreement with the conclusion that band width in novae is roughly proportional to luminosity.

Detailed study of individual nebulae indicates that the unresolved elliptical nebulae are probably clusters of stars with a range of spectral type not exceeding one or two spectral classes.

Concerning the problem of the interpretation of the red shift two important advances have been made. Firstly, an analysis of the observational material of Hubble and Tolman indicates that, if the red shift is to be interpreted on the basis of radial velocity, a spatial curvature must be introduced with a radius within the observing range of the 100-inch telescope. Secondly, an observation of the red shift of one of the brighter nebulae with a grating instrument (the first such to be made) yields the same displacement as that measured on prism spectrograms; which disproves the suggestion that the frequency of a light source might vary while the wavelength remained constant, that is, the suggestion that the velocity of light might not be constant throughout its passage from the nebula.

The Galaxy. Measures of the colours of globular clusters by Stebbins and Whitford interpreted on the basis of interstellar absorption reduce the estimated overall diameter of the galaxy by about one-half, or to 30,000 parsecs (100,000 light years); which removes an apparent discrepancy between the size of our galaxy and that of other systems.

An interesting correlation has been established between the colours of stars and the number of extragalactic nebulae observed in various parts of the sky, the stars being considerably redder where extragalactic nebulae are few. Interpreted on the basis of partial obscuration, this indicates that space reddening is greater toward the centre of the galaxy and that obscuring matter in that direction

becomes appreciable at 1,000 parsecs, which is only one-tenth the distance of the galactic centre.

In the search for stars of the extreme dwarf class one of especial interest, Ross 627, a white dwarf of luminosity about one two-thousandth that of the sun has been noted.

Certain lines in the yellow and red regions of the spectra of distant stars have been found by Merrill to have interstellar origin like the well-known interstellar lines of calcium and sodium.

The Sun. The Observatory's routine program of solar research has been extended by the addition of a continuous series of small-scale hydrogen spectroheliograms made automatically every four minutes. This series is of particular interest in the study of bright hydrogen eruptions, occurring in the neighbourhood of sun-spots, which apparently have an intimate connection with radio fade-outs.

Measured velocities of eruptive prominences have shed some new light on their laws of motion. In particular it has been discovered that the new velocity of a promience following a sudden acceleration is a small multiple of the preceding velocity, and two or three separate accelerations during the life of a prominence are not uncommon.

Laboratory Research. The Physical Laboratory has retained its close relation to the problems of astronomy. Particular attention has been paid to the analysis of the spectra of the rare earths. As well, King has made a spectroscopic analysis of 13 meteorites which has greatly extended our knowledge of the constitution of the various classes of meteorites.

J. F. H.

Preliminary General Catalogue of Comets, by A. S. Yamamoto. Publications of the Kwasan Observatory, Volume I, No. 4. Kyoto, Japan.

The Kwasan Observatory of Kyoto Imperial University is preparing a comprehensive general catalogue of comets, which will contain all published orbits of all comets. In the meantime A. S. Yamamoto publishes this preliminary catalogue, which gives for each comet only one of the best orbits. It is a revision of an earlier catalogue, published in Japanese by Professor Issei Yamamoto.

In this catalogue there are tabulated 647 apparitions of comets, up to 1936 c. These represent 467 different comets. The comets are listed according to date; the current number of the apparition, the serial number of the comet, its discoverer, the elements of the orbit, and the references to the published orbits, are tabulated. An appendix lists the periodic comets, with their predicted dates of their next perihelion passage, the computed dates of past apparitions, and whether the comet was actually seen at these times.

As the angular elements are given in degrees and decimals, tables are included for transforming angles from the decimal to the sexagesimal system.

This compact table should be very convenient for quick reference to comet orbits.

F. S. H.

Galactic Atlas, by K. F. Bottlinger and Irmgrad Beck, 8 plates with a galactic conversion table, published by Julius Springer, Berlin W 9. Price 15 R.M.

The plan of this atlas originated with K. F. Bottlinger to provide a ready method of obtaining the galactic positions of the brighter stars and interesting objects in the sky. He did not live to see the atlas completed but his original plan has been followed out by Miss Irmgard Beck. The atlas consists of eight maps covering the entire celestial sphere. The axis of projection is the line joining the galactic poles and two polar maps cover the regions around these poles from galactic latitudes $+45°$ to $+90°$ and $-45°$ to $-90°$. Six galactic equator maps extend from galactic latitude $+50°$ to $-50°$. A network of the right ascension and declination circles is superimposed in light red and the outlines of the constellations as determined by the International Astronomical Union are shown in the same colour.

The material of the atlas comprises the following objects which are plotted for the equinox of 1900: the brighter stars to magnitude 5.5 with their spectral types, the largest and brightest star clusters, spiral nebulae, novae, planetary nbeulae, diffuse nebulae. Stars are listed with the Flamsteed number and the types are taken from the Henry Draper catalogue. The N.G.C. number is given for the star clusters and nebulae. The dark nebulae are numbered

according to Barnard. Generous use is made of symbols to indicate the character of variable stars such as Cepheid, irregular, RR Lyrae type, etc. The scale of the maps is approximately 2 cm. per 10 degrees.

In addition to the charts a table is included for the conversion of equatorial to galactic co-ordinates. The intervals in the table are every half hour of right ascension and every 10 degrees of declination.

R. K. Y.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Toronto Centre Variable Star and Nova Programme Observations, April 1937.

The amateur observers of the Toronto Centre of the R.A.S.C. have organized themselves into sections, with the desire to make observations which will be of permanent value. A great deal of the credit for spurring these enthusiasts on to making and reporting observations is due to the interest aroused by Mr. D. W. Rosebrugh's pamphlet "How Amateurs Make Observations Upon Variable Stars". One of the sections is for observers who wish to make magnitude estimates of variable stars, or search allotted areas for novae, or both. This observing section now boasts a membership of seven, four of whom have sent in a report of their observations for the month of April. These reports appear below in detail to show how such observations should be recorded. It is hoped that when others realize the simplicity of these data, they will catch the enthusiasm of these observers. Henceforth, however, a summary only, will be published in this Journal, since the observations are all sent on to the A.A.V.S.O., and will therefore appear in print elsewhere.

Anyone interested in making observations such as these, will be supplied with charts and information by the director of the section. No optical aid is necessary to become a nova searcher, while binoculars, or a small telescope allow one to make observations of variables.

May 4, 1937.
David Dunlap Observatory.

F. Shirley Patterson,
Director.

VARIABLE STAR OBSERVATIONS—April 1937

Observer—RUTH J. NORTHCOTT
71 Joicey Blvd.
Toronto

Instrument—2-in. refractor, 8 x

Date	E.S.T. (P.M.)	J.D.	Designation	Variable	Est. Mag.	Mag. of Comparison Stars
Thur. 29	9 43	2428653.613	094211	R Leonis	6.2	6.4, 5.8
Fri. 30	10 02	2428654.626	094211	R Leonis	6.2	6.4, 5.8

Observer—BERT TOPHAM
105 Regent St., Toronto 9

Instrument—6½-in. refractor, 80 x

Date	E.S.T. (P.M.)	J.D.	Designation	Variable	Est. Mag.	Mag. of Comparison Stars
Fri. 16	9 30	2428640.6	103769	R Ursae Maj.	8.6	8.2, 8.8
Fri. 16	9 50	2428640.6	094211	R Leonis	6.1	5.8, 6.4
Fri. 16	10 47	2428640.7	103769	R Ursae Maj.	8.6	8.2, 8.8
Mon. 19	9 45	2428643.6	163137	W Herculis	9.4	9.4, 9.2
Thur. 29	9 00	2428653.6	072708	S Canis Min.	9.8	10, 9.7
Thur. 29	10 00	2428653.6	094211	R Leonis	6.4	6.4, 5.8, 6.6
Thur. 29	10 30	2428653.6	103769	R Ursae Maj.	8	7.7 8.2
Thur. 29	11 00	2428653.6	162119	U Herculis	10.9	10.4, 10.8

Observer—NEIL MCNABB, Jr.
Acton, Ontario

Instrument—2-in. refractor
—opera glasses

J.D.—75th Mer.	Designation	Variable	Est. Mag.
2428632.7	154428	R Cor. Bor.	6.0
2428634.7	154428	R Cor. Bor.	6.0
2428635.7	094211	R Leonis	6.4
2428636.7	154428	R Cor. Bor.	6.0
2428637.7	154428	R Cor. Bor.	6.0
2428638.6	094211	R Leonis	6.4
2428639.7	154428	R Cor. Bor.	5.8
2428639.7	103769	R Urs. Maj.	8.8
2428642.7	154428	R Cor. Bor.	6.0
2428652.6	154428	R Cor. Bor.	5.8
2428654.6	094211	R Leonis	6.9
2428654.7	154428	R Cor. Bor.	5.8
2428654.7	103769	R Urs. Maj.	8.0

NOVA SEARCH OBSERVATIONS—April 1937

Date	P.M. E.S.T.	J.D.	Area	Faintest Mag.
Observer—Ruth J. Northcott				
Instrument—Binoculars, 20 mm.				
*2″ refractor, 8x				
Mon. 12	8 45	2428636.57	71	7
	9 15	2428636.59	9	6
Fri. 16	8 50	2428640.58	9	6
	9 00	2428640.58	71	6
Mon. 19	11 10	2428643.67	71	6
Thu. 29	9 20	2428653.60	71	7*
Fri. 30	9 25	2428654.60	71	7*
Observer—Bert Topham				
Instrument—none				
Thu. 29	8 25	2428653.6	91	4
Observer—Neil McNabb, Jr.				
Instrument—Opera Glasses				
—*20 mm. refractor, 6x				
		2428632.7	58	6
		2428634.6	72	7
		2428634.8	58	7
		2428635.7	72	7
		2428635.7	58	7
		2428636.7	72	6
		2428636.7	58	6
		2428637.7	72	6
		2428637.7	58	6
		2428638.6	72	6
		2428638.6	58	6
		2428639.6	72	6
		2428639.6	58	6
		2428639.7	58	7
McNabb's Obs. Cont'd.				
		2428640.6	72	6
		2428640.7	58	6
		2428642.7	58	6
		2428642.7	72	6
		2428643.7	72	6
		2428643.7	58	6
		2428652.6	72	7
		2428652.6	58	7
		2428653.7	72	7
		2428653.7	58	7
		2428653.7	8	6
		2428654.7	72	7-8*
		2428654.7	58	7
		2428654.7	8	6
Observer—F. Shirley Patterson				
Instrument—none				
Fri. 16	8 15	2428640.6	70	]5
	8 30	2428640.6	18	4.5
Mon. 19	9 30	2428643.6	18	5.0
	9 45	2428643.6	70	]5.0

MEETINGS OF THE SOCIETY

AT TORONTO

March 23, 1937.—The regular meeting of the Royal Astronomical Society, Toronto Section, was held in McLennan Laboratory on March 23, 1937, Mr. E. J. A. Kennedy in the chair. The minutes of the previous meeting were read and adopted.

The following persons were elected to membership in the Toronto Section:

Mr. Clarence H. Magee, 182 Walmer Road, Toronto.
Mr. Walter Vohman, 31 Scott Road, Toronto.

The librarian asked for books on loan from the library to be returned for reclassification.

The speaker of the evening, Rev. D. W. Best, gave a splendid description of astronomical objects in his talk "Near and Far in the Heavens". He pointed out that the terms "near" and "far" are relative terms, according to the system under consideration. For example, in the solar system the moon is near and the sun is far; in the extra-galactic system the stars of the Milky Way are near and the nebulae far. Dr. Best pointed out that similar forces are at work in the satellite systems of the planets and in the solar system as a whole. There are three hypotheses of the evolution of such systems: Laplace's Nebular Hypothesis, Jeans' Tidal Theory of two bodies, and the three body theory, which is not yet completely developed.

The form of the galaxy and the types of objects present in it were discussed. It was pointed out that Cepheid variables are important as yard-sticks, and that star streaming is due to the rotation of the stars about a remote centre. In the case of the B-type stars, the distance of the centre is 30,000 light years, and the period of rotation is 225 million years.

The distribution and form of the "far" objects, the spirals, were described. Spectra give a vast amount of information about the celestial objects, both near and far. Dr. Best concluded with a brief discussion of the four generations of the tidal theory: chaos, the spiral nebulae with a central nebulous mass, the system of planets and the satellites of the larger planets.

The second speaker, Mr. Duncalfe, pointed out the constellation Orion is useful in fixing the positions of the right ascension and declination circles in the sky. δ Orionis is very nearly on the equator. The whole constellation lies between 5 and 6 hours of right ascension. Mr. Duncalfe also discussed the optical illusion of the rising or setting sun or moon appearing larger than when these objects are on the meridian. He gave Edmund Beckett's explanation of the phenomenon.

A short reading by Mr. Hooker described such wonders of Astronomy as would tend to induce visitors present to wish to become members of the society.

The death of Prof. L. B. Stewart, one of the oldest members and a former president of the Society, was brought to the attention of the members. It was decided that condolences should be sent to the family.

Members were reminded of the formation of observing groups.

RUTH J. NORTHCOTT, *for Recorder.*

April 6, 1937.—The regular meeting of the Toronto Section of the Royal Astronomical Society of Canada was held on the evening of Tuesday, April 6, 1937, in the McLennan Laboratory, University of Toronto, with Mr. E. J. A. Kennedy in the chair.

The assistant librarian reported that she had a recent publication of the University of Michigan, describing in detail the new McMath-Hulbert solar tower.

Mr. Kennedy read a news item concerning the expedition which is going to attempt to land on a Pacific coral island to study, and broadcast to the world, details of the forthcoming eclipse of June 8.

Mr. A. R. Hassard the first speaker of the evening, in his paper, "Some Stars I Have Liked", told us interesting details about many doubles and clusters, in several well known constellations. He mentioned Polaris, γ Andromedae, γ Arietis, the Hyades, Pleiades, Praesepe, the Coal Sack, Castor, β Cygni and many other objects, which make a beautiful sight in a small telescope, and which may also be used as criteria in determining the quality of the seeing.

Mr. Collins again reminded the members of the observing sections to which they could belong, and Miss Patterson gave a report of the observations made by Mr. Neil McNabb on variable stars and novae search programmes, during the month of March.

Mr. Combs then delighted us with two reels of motion pictures. The first in colour, taken by himself, included views of the spring floods in the Maritimes, scenic highlights along the Pacific coast, and sunset views. The second reel showed us life at the bottom of the ocean, an ant colony at work, and fight between a mongoose and a cobra. All these were greatly appreciated.

April 20, 1937.—The regular meeting of the Toronto Section of the Royal Astronomical Society of Canada, was held on the evening of April 20, in the McLennan Laboratory, University of Toronto. Mr. E. J. A. Kennedy, Chairman, presided.

The minutes of the last meeting were read by Mr. D. A. MacRae, and duly adopted.

Mr. Clifford N. Forster, 38 Brownlow Ave., Toronto, was elected to membership. Mr. Kennedy reported that the renovation of the library was nearing completion.

The paper of the evening, by Miss F. S. Patterson, M.A., was a review of "The Realm of the Nebulae" by Edwin P. Hubble. Mr. Hubble presents his problem from the viewpoint of the observer, that scientific worker who collects observational data and analyzes it by graphical methods.

The introduction contains an explanation of the various technical terms used throughout the book. Among these are units of distance, magnitudes, the period-luminosity relation for Cepheids, and the method of designation of the nebulae. In the first chapter, Mr. Hubble gives a general survey of the problem and its results, tracing its formulation through the work of Galileo, Herschel and Huggins, to its solution by the workers with the 100-in. at Mt. Wilson. The remainder of the book presents the methods of investigation and discussion of the results in detail. Investigations were made concerning the features of the individual nebulae, and concerning the character of the whole of the observable region, the realm of the nebulae. The first of these investigations showed that the regular nebulae were closely related members of the same family. They follow a fundamental pattern, which varies consistently from compact elliptical nebulae to open barred or normal spirals.

The study of the whole of the observable region of space yielded two major results,—the uniform distribution of the nebulae in space, and the velocity-distance relation. Nebular surveys to a given limit gave the distribution over the sky, which was found to be isotropic, after correction had been made for obscuration due to clouds of dust and gas in the plane of our galaxy. Other surveys to successive limits of magnitudes gave the distribution in depth. It was found that on the average, each nebula was two million light-years from its nearest neighbour; that is, if the nebulae were the size of tennis balls, they would be 50 feet apart. The slight tendency for the nebulae to group and cluster disappeared in the large-scale averages. The nebulae were found to be galaxies comparable in both size and composition to our own. The red-shifts of the lines in the spectra of the nebulae, when interpreted as velocities were found to vary linearly with the distances, as determined by Cepheids and the brightest star methods.

A whole chapter was devoted to a detailed study of the Local Group, which includes our galaxy and its satellites, the Magellanic Clouds, the Great Andromeda Nebula and its neighbours M32 and N.G.C. 205, as well as two irregular nebulae and M33, a massive late type spiral, considered very similar to our own.

In studying the general field nebulae, the brightest stars in the spirals were the key to the distances. In all nebulae, local ones included, these stars were found to have very nearly the same absolute magnitude, which could be determined from near-by nebulae. Hence their apparent magnitude in any resolvable nebula, gives an idea of the distance of that spiral. The realm of the nebulae is observable out to distance of 500 million light-years. The apparent velocities are positive and large, increasing with distance, giving us foundation for the theory of the expanding universe. However time may bring us another interpretation of the red-shifts, which will be less disturbing to the theorist.

A discussion followed the paper; Mr. Collins made the relative sizes of the nebulae and the observable region of space more explicit; while Mr. Brown explained the Doppler effect.

Mr. Topham of West Toronto, sent in observations of Mercury, Venus and the Moon, all three being close together in the sky on a recent evening. Several members, Mr. Hooker, Mr. Duncalfe, Dr. Best and others, reported observations.

of quite a spectacular display of solar haloes and sun-dogs, visible for several hours in the late afternoon, April 20th. Mr. Donald A. MacRae measured the radius of the inner halo to be about 22°, and succeeded in obtaining a photograph showing two of the dogs.

Mr. Troyer brought to our attention the periodical "The Sky", published by the Hayden Planetarium.

May 4, 1937.—The regular meeting of the Toronto Centre of the Royal Astronomical Society of Canada, was held on Tuesday evening, May 4, in the McLennan Laboratory, University of Toronto, Mr. J. R. Collins presiding.

The minutes of the last meeting were read and adopted. Miss Budd read a report of the periodicals received in exchange for the JOURNAL, and announced that the books in the library were once more available to members.

The speaker of the evening, Dr. F. S. Hogg, of the Department of Astronomy, University of Toronto, told us in his paper on "Solar Eruptions and Their Effects on Radio Reception", of the size, kinds, speeds and prevalence of prominences on the sun. He then described the correlations found to exist between the strength and numbers of sunspots and prominences with terrestrial magnetic storms, aurorae, and radio fadeouts. Outlining the part the Kennelly-Heaviside layer plays in radio transmission, he showed how the high speed particles and ultra-violet radiation shot out by the sun, might alter its height, and hence change the paths of radio waves. The spectroheliograph at Mt. Wilson makes a continuous record of the prominences, so that the times of their appearance may be compared with those of disturbances in radio reception. A discussion followed the lecture.

Observations on Friday, April 30, of sunspots arranged in a large group, with the appearance of being linked together were reported. The April report of the variable star and nova search observing section was read.

Mr. Duncalfe then illustrated with a scale drawing, the fact that though the moon revolves around the earth, its path is always concave to the sun. He also showed us how the moon's librations are due to the inclination and eccentricity of the moon's orbit. A close watch of the crater Plato, makes the moon's librations readily noticeable.

Mr. Collins announced that this was the last regular meeting of the season.

F. SHIRLEY PATTERSON, *Recorder.*

AT WINNIPEG

March 10, 1937.—Dr. L. A. H. Warren's address was on our Sun, in which he was assisted by Prof. J. W. Lawson with slides. Incidental references were made to the previous lecture, and several slides shown from the spectroheliograph gave the appearance of the sun's surface as regards distribution of hydrogen, vapourized iron, helium and calcium. The general calcium tints showed as white; the hydrogen quite black. Considerable attention was devoted to sun-spot phenomena, and evidence produced that the spots possessed polarity, so that extrusions of flame in the chromosphere appeared drawn back into the sun

at various spots. The spots were more frequent in what corresponded to our temperate zones, and the maxima had a period of about 11 years. Effect on terrestrial magnetism was definite; the effect on weather though possible was very subordinate to other factors and hardly predictable.

Passing to stars in general, the somewhat complicated system of "magnitudes" was explained; likewise the improved method of comparing stars by "absolute magnitude" by which they were all (in imagination) placed at a distance of 32 light-years (10 parsecs). Some of those with great absolute magnitude nevertheless had low surface-luminosity; Betelgeuse and Antares were named in this connection. These are two large red stars with diameters theoretically thousands of times the diameter of the sun though their substance is of extreme rarity. We further understood that stars fall into several classes, such as blue, white, dwarf-white and red; the dwarf whites were possibly in even a further state of decay than the red stars; the reds and yellow-reds occupying a medium position. It was conceivable that under some conditions stars continued to grow cold; but explosions of apparently decaying stars sometimes occurred, so that it was hard to say whether a bluish-white star was young or old and had exploded.

April 14, 1937.—A Meeting of the Winnipeg Centre on April 14th was presided over by Mr. Darracott. This being "Members' Night" three short addresses were given on the subject of our Moon. That by Miss O. A. Armstrong covered the probable origin, according to the Planetesimal Theory; its lack of atmosphere and general surface characteristics; a blackboard demonstration of Newton's calculation of its mass in tons, comparison of light reflected to earth at full and half-moon with sunlight, etc.

Dr. M. F. Bennett used a scale model of about five feet radius to demonstrate eclipses (with flashlight); then using larger spheres discussed the phases; and finally its path in space under solar and terrestrial forces, stating that to a very distant observer it would describe a path essentially parallel to that of the earth, with deviations right and left which are scarcely significant.

Mr. G. P. Morse, rejecting the artificial parallax formula, discussed the evolution of base-lines for calculating the distance to the moon; thence the subsequent tabulation of parallax. In view of the recent production of highly sensitive film, he also suggested the use of photography at the time of an eclipse of the moon by tele-photographic camera, and thought that with a 5 seconds exposure there would be data for at least an amateur estimation of diameter.

The audience included a contingent from St. Paul's (boys') college.

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